Attachment 7

Guidance for Fire Growth and Damage Time Analysis

General Caution Regarding Complex Fire Growth Scenarios
The fire modeling tools provided to support the Phase 2 fire growth and damage time analysis are relatively simple correlation-based modeling approximations. These tools cannot handle all fire growth conditions accurately. When a scenario presents complicated fire growth conditions, this scenario is a potential candidate for a Phase 3 assessment.

Fire Growth and Damage Time Analysis - FDS1 Scenarios

The time to damage for FDS1 scenarios is based on the effects of heating in the fire plume and/or direct radiant heating. Fire spread to secondary combustibles may also be a concern.

Plume heating
For fire plume exposures, the plume temperature at the target location is estimated. The plume temperature correlation gives a single value result based on the height above the fire source and fire intensity (HRR). Another factor that must be input is the convective fraction of the heat release.

Plume temperature analysis correlation
The plume temperature correlation used in the SDP is described in detail in Chapter 9 of NUREG-1805. The **Plume_Temperature_Calculations.xls** spreadsheet is used to calculate centerline temperature of a buoyant fire plume.

Inputs required for use of this correlation are also described in detail in NUREG-1805, and are summarized as follows:

- Heat release rate of the fire (kW)
- Distance from the origin to the target within the plume (ft)
- Surface area of the combustible fuel (ft^2) [Use 6.0 ft^2 as a standard value.]
- A value of 0.7 is used for the convective fraction

For certain specific physical configurations, the HRR utilized in the fire plume correlation must be adjusted. In particular, close proximity of the fire ignition source to a wall or corner amplifies the effects of the plume as follows:

- For a fire in an open area (away from walls or corners) the nominal fire heat release rate (HRR) is used,
- For the same fire next to a wall, multiply the nominal HRR by two,
- For the same fire in a corner, multiply the nominal HRR by four.

Given an exposure temperature, the time to damage for thermoset and thermoplastic cables, respectively, is estimated in the following tables:

Table A7.1 - Failure Time-Temperature Relationship for Thermoset Cables		
Exposure Temperature		Time to Failure (minutes)
°C	°F	
330	625	28
350	660	13
370	700	9
390	735	7
410	770	5
430	805	4
450	840	3
470	880	2
490 (or greater)	915 (or greater)	1

Table A7.2 - Failure Time-Temperature Relationship for Thermoplastic Cables		
Exposure Temperature		Time to Failure (minutes)
°C	°F	
205	400	30
220	425	25
230	450	20
245	475	15
260	500	10
275	525	8
290	550	7
300	575	6
315	600	5
330	625	4
345	650	3
355	675	2
370 (or greater)	700 (or greater)	1

Radiant heating

The approach for radiant heating is similar to that for plume heating. An exposure heat flux is calculated using the appropriate fire modeling correlation from NUREG-1805 fire modeling tool set, and the damage time is assessed base on the intensity of the exposure. The inspector must establish the line of sight distance from the fire to the target. A second factor required is the fraction of the total fire heat output that is released as thermal radiation.

- For evaluating damage due to radiant heat, assume 30% of heat released by fire is radiant energy (radiant fraction = 0.3).

Radiant heating correlation

The correlation for estimating fire radiant heating effects is described in detail in Chapter 5 of NUREG-1805. Only the Wind Free Condition correlation is applied in the Phase 2 SDP process. The following spreadsheet from NUREG-1805 applies:

- Wind Free Condition (i.e., indoor fires): **Heat_Flux_Calculations_Wind_Free.xls** (Click on Point Source)

Inputs required for use of this correlation are also described in detail in Section 5.6 of NUREG-1805, and are summarized as follows:

- Fuel type (material)
- Fuel spill area or dike area (ft^2)
- Distance between fire and target (ft)
- Vertical distance of target from ground level (ft) [For Solid Flame 2 calculation]

Once the exposure heat flux has been estimated, the time to damage due to exposure heat flux for thermoset and thermoplastic cables, respectively, is estimated in the following tables:

Table A7.3 - Estimated Damage Time for Radiant Heating Exposures - Thermoset Cables		
Exposure Heat Flux		**Damage Time (minutes)**
BTU/ft^2s	**kW/m^2**	
<1.0	<11	No Damage
1.0	11	19
1.2	14	12
1.4	16	6
1.6	18	1
1.75 or greater	20 or greater	1

Table A7.4 - Estimated Damage Time for Radiant Heating Exposures - Thermoplastic Cables		
Exposure Heat Flux		**Damage Time (minutes)**
BTU/ft^2s	**kW/m^2**	
<0.5	<6	No Damage
.5	6	19
.7	8	10
0.9	10	6
1.0	11	4
1.25	14	2
1.4 or greater	16 or greater	1

Fire Growth and Damage Time Analysis - FDS2 Scenarios

The analysis of time to damage for FDS2 fire scenarios will be dominated by one of the following four factors:

- The time required for fire to grow to a sufficient size and intensity so as to create a damaging hot gas layer exposure condition,
- The time required for the fire to spread to a critical location damaging exposed fire damage targets,
- The time required to cause damage to components or cables protected by a moderately degraded fire barrier system, or
- A non-degraded fire barrier system with a fire endurance rating of less than two hours.

Fire growth creates a damaging hot gas layer

In some scenarios, fire damage will occur due to a hot gas layer exposure, but only after the fire spreads beyond the fire ignition source. The fire ignition source itself may not be of sufficient intensity to create a damaging hot gas layer, but if the fire spreads to secondary combustible, then a damaging hot gas layer could be created.

In such situations the secondary combustible is likely to be cables. Common examples include a hot work fire that ignites a cable tray, a self-ignited cable tray fire, a transient fire that ignites one or more cable trays, or an electrical equipment fire that ignites one or more cable trays.

The Fire Dynamics Tool Hot Gas Layer correlation is applied.

- Increase (or decrease) the fire HRR in increments of 50 kW until the hot gas layer temperature predicted at 10 minutes is above the appropriate cable damage threshold (i.e., thermoplastic or thermoset).
- Subtract from the resulting fire intensity, the fire intensity of the postulated fire ignition source.
- The remainder of the fire frequency must be accounted for by fire spread, presumably into overhead cable trays (the “fire spread HRR”):
    - Assume a that a cable tray will burn at an intensity of 400 kW/m^2
    - Divide the fire spread HRR (in kW) by 400 to determine the square meters of cable tray required to create a fire of this intensity.
    - Determine if there are sufficient cable trays available to support a fire of this size. *If the available cable trays are not sufficient to support the required fire intensity (there are not enough exposed trays), then this hot gas layer FDS2 fire scenario is determined to be implausible, and should be discarded. Consider possible FDS2 scenarios that involve direct spread of fire to the necessary target set (see discussion below).*
    - If the trays present are sufficient, apply the fire spread rules for cable tray fires and estimate the time required for the fire to spread to this size (e.g., following the rules for horizontal and vertical fire spread, and for spread to adjacent cable stacks).
    - This time is taken as the FDS2 hot gas layer scenario fire damage time.

Fire spreads to the location of an exposed fire damage target

In some scenarios, the mechanism for fire damage may be the spread of fire from a fire ignition source to the location of a critical target. In this case, it is likely that fire spread through one or more cable trays will be the concern. A typical case might involve a fire ignition source that ignites cables directly overhead, and the subsequent spreads of fire through the tray(s) to the location of a cable “pinch point” where the routing of a target cables converge with the fire spread path.

In such cases, the fire damage time is determined by the time required to spread fire to the target cable location. Once fire spreads to the target, no additional failure time delay is assumed (due to pre-heating of the cable during the period of fire spread).

The rules for the analysis of cable tray fires to estimate the required fire spread time are provided in Attachment 3.

<u>Fire causes failure of a localized or raceway fire barrier</u>
A prolonged fire is postulated to cause the failure of a localized fire barrier protecting cables or components. This damage mechanism is relevant in the following example cases:

- <u>A moderately degraded fire barrier that is given some credit for fire protection</u>: For a moderately degraded barrier, the fire endurance rating is reduced to reflect the degradation. The fire barrier system would typically be protecting required or associated circuit cables where the Appendix R Section III.G.2 protection strategy involved a three-hour fire barrier wrap, or a one-hour wrap plus detection and suppression.

- <u>A non-degraded raceway fire barrier system protecting important safe shutdown system with a rating of less than two hours</u>: In this case, the barrier may be associated with an exemption or exception to the separation requirements of Appendix R Section III.G.2, or that analysis may involve a finding against other aspects of the III.G.2 requirements (e.g., the fire detection and/or suppression systems).

Given a damaging fire exposure condition, it is assumed that the cables will fail in a time equal to the fire endurance time of the fire barrier system as reduced by the noted degradation plus one-half the time to damage normally associated with the fire exposure conditions using the appropriate table provided in this Attachment.

> Example 1: A particular cable tray containing thermoplastic cables is wrapped with a fire barrier system that has a nominal 1 hour fire endurance rating. The barrier system is degraded, and the degradation rating was “Moderate B.” Given the degradation, the 1 hour fire barrier fire endurance rating is reduced to 21 minutes (35% of the nominal performance rating). It was determined that the fire plume for a given fire ignition source creates a potentially damaging fire exposure condition with an exposure temperature of 245°C (475°F). The damage time at this exposure temperature taken from the Failure Time-Temperature Relationship for Thermoplastic Cables Table above is 15 minutes. Hence the net damage time for the protected cables is (21+15/2) = 28 minutes. *(Note: The time to damage is rounded down to the nearest minute.)*

> Example 2: A particular cable tray containing thermoplastic cables is wrapped with a fire barrier system that has a 20 minute fire endurance rating. The barrier system is not degraded, but failure of the protected cables could impact post-fire safe shutdown. It was determined that the fire plume for a given fire ignition source creates a potentially damaging fire exposure condition with an exposure temperature of 245°C (475°F). The damage time at this exposure temperature taken from the Failure Time-Temperature Relationship for

Thermoplastic Cables Table above is 15 minutes. Hence the net damage time for the protected cables is (20+15/2) = 27 minutes. *(Note: The time to damage is rounded down to the nearest minute.)*

Example 3: The licensee separation compliance strategy utilized a one-hour fire barrier wrap plus automatic detection and suppression. The fire suppression system was found to be highly degraded, and will not be credited in the analysis. The fire barrier is not degraded and will be given full credit in the analysis. One identified FDS2 scenario involves failure of the cables within the wrapped raceway. It was determined that a fire involving a particular fire ignition source can create a damaging plume exposure condition. The minimum time to fire damage for this FDS2 scenario is one hour.

Fire Growth and Damage Time Analysis - FDS3 Scenarios

Given the screening criteria used in Tasks 1.3.2 and 2.2.2, FDS3 fire scenarios will only be analyzed under very specific and limited conditions. FDS3 scenarios are relevant under one of the following three cases:

- Any high degradation fire confinement finding,
- A moderate degradation fire confinement finding that did not meet the finding screening criteria of Task 1.3.2, or
- A finding other than fire confinement that did not meet the FDS3 screening criteria of Task 2.2.2.

These three cases are each treated somewhat uniquely.

High Degradation Fire Confinement Finding

For a high degradation fire confinement finding, a fire barrier separating two fire areas is assumed to provide no fire protection benefit. In this case, the only FDS fire scenario(s) being considered will be the FDS3 scenario(s).

In this case, treat the two fire areas normally separated by the degraded fire barrier as a single expanded fire area.

Define a set of FDS3 fire scenarios using the rules normally applied in to define FDS2 fire scenarios (see Step 2.5). Fire ignition sources in both fire areas are counted and considered to estimate fire frequency and in developing fire scenarios. All defined scenarios must involve damage to targets located in both fire areas.

The newly defined FDS3 scenarios are evaluated using the same tools applied to FDS2 fire scenarios (see FDS2 scenario analysis guidance). All fire ignition sources existing in both fire areas are included in the fire analysis.

Include credit for any fixed fire detection or suppression systems installed in either fire area using the general guidance already provided. For any given fire scenario credit no more than one fixed fire suppression system (i.e., credit only that fire suppression system that provides protection for the postulated fire ignition source).

Moderate Degradation Fire Confinement Finding

For a moderate degradation fire confinement finding the degraded fire barrier is given some credit for confining fires to the room of fire origin. In this case, the only fire scenario(s) being considered will be the FDS3 fire scenario(s).

The fire endurance rating of the inter-compartment fire barrier is reduced to reflect the degradation (to either 65% or 35% of the nominal fire endurance rating for Moderate A and Moderate B respectively).

Based on the screening rules used in Task 1.3.2, the fire areas being analyzed will also display the following characteristics (or else the finding would have screened to green in Phase 1):

- The fire endurance rating of the degraded fire barrier is limited and implies further conditions:
    - At most, the fire endurance rating is less than 2 hours.
    - If the fire endurance rating of the degraded barrier is 20 minutes or more, then there are in-situ fire ignition sources or fire spread paths that can lead to direct flame impingement onto the degraded barrier.   In this case, focus on these fire sources and fire growth scenarios.
    - If the fire endurance rating is less than 20 minutes, there are still potentially damaging fire ignition source present or the finding would have screened out in Step 2.4 (no challenging fire scenarios).

- Fixed fire suppression capability in the exposing fire area is limited, non-existent, or non-functional so fixed fire suppression in the exposing fire area will not credited:
    - A limited coverage system that does not cover all in situ combustible may exist. In this case, consider only the fire ignition sources not provided with suppression coverage and do not credit fixed suppression.
    - The fire area may have no fixed fire suppression capability, or
    - The installed fixed fire suppression system is highly degraded.

- The exposed fire area <u>does</u> contain fire damage targets that are unique from those in the exposing fire area and:
    - Damage targets are exposed (un-protected), or
    - Damage targets are protected by passive fire barriers with an effective fire endurance rating of less than 20 minutes (this also covers the credit given a moderately degraded raceway fire barrier).

Select/define no more than two fire ignition source / fire growth scenarios to represent all fires for the FDS3 fire scenario. If possible:

- One scenario is chosen that will create a damaging hot gas layer, and/or
- One scenario is chosen that will lead to fire spread up to, and direct flame impingement on, the degraded fire barrier.

If no fire scenario can be developed that satisfies one or both of these conditions, the FDS3 fire scenarios are deemed to be incredible, and the finding screens to green.

Fire growth and damage times are estimated using the FDS2 analysis tools and rules. Determine the time required to:

- Create a damaging hot gas layer in the exposing fire area, and/or
- To spread fire to the point where flames will directly impinge on the fire barrier (e.g., fire spread along a cable tray).

Choose the one fire scenario that conservatively bounds these two cases in terms of the fire growth and damage times. The corresponding time is taken as the fire growth time.

Assume the fire barrier will successfully confine any fire to the exposing fire area for a period equal to the degraded fire endurance rating. Add the effective fire endurance rating of the degraded fire barrier to the fire growth time.

Add to this time the fire endurance rating for any raceway fire barriers protecting the targets in the exposed fire area.

The result is the total fire damage time:

(fire damage time) = (fire growth time)+(effective fire endurance rating for the inter-compartment fire barrier)+(effective fire endurance rating for raceway fire barriers in the exposed area if available).

Continue to step 2.7 using the following assumptions:

- Use the "All Events" manual suppression curve estimate fire non-suppression probability regardless of the fire ignition source.
- Fixed fire suppression capability may be available in the exposed fire area and may be credited as follows:
    - If a non-degraded water-based automatic fire suppression system installed in the exposed fire area, and the system provides coverage in the area immediately adjacent to the degraded fire barrier, it will be credited for fire suppression prior to damage using the nominal reliability of 98% (0.02 failure probability) without explicit consideration of actuation timing.
    - If a moderately degraded water-based automatic fire suppression system is installed in the exposed fire area, and the system provides coverage in the area immediately adjacent to the degraded fire barrier, it will be credited for fire suppression prior to damage at a reduced reliability of 90% (0.1 failure probability) without explicit consideration of actuation timing.
    - No other fixed fire suppression capability in the exposed fire area will be credited.

<u>Findings Other than Fire Confinement</u>

For a finding other than fire confinement, the FDS3 fire scenario(s) will not be the only fire scenarios being analyzed. One or more FDS1 and FDS2 fire scenarios should already have been developed.

FDS3 scenarios do not need to be considered for this case if the analysis:

- Was unable to identify any credible FDS2 damage scenarios, <u>and</u>
- Did not identify any FDS1 scenarios the could lead to direct flame impingement on the degraded fire barrier.

If these conditions are met, proceed to Step 2.7. The FDS3 fire scenarios will not be considered credible and need not be further analyzed.

Based on the screening rules used in Task 2.2.2, the exposing and exposed fire areas will also display the following characteristics (or else the finding would have screened to green in Phase 1):

- The fire endurance rating of the inter-area fire barrier will be less than two hours, but the barrier should note be degraded and will be given full credit for containing fires to the exposing fire area for a time equal to the fire endurance rating.
- There will be no non-degraded fixed fire suppression capability in either the exposing or the exposed fire area. Fixed fire suppression systems will not be analyzed.
    - No credit is given to a highly degraded water based system given.
    - A degraded gaseous system either (moderate or high) may be present but will not be credited in the FDS3 scenarios. Fixed fire suppression capability may be available in the exposed fire area.
- The exposed fire area <u>does</u> contain exposed (un-protected) fire damage targets that are unique from those in the exposing fire area.

One fire scenario will be selected to represent the FDS3 fire scenarios. The representative scenario will be chosen from the following cases:

- Any FDS2 fire scenario associated development of a hot gas layer.
- Any FDS1 or FDS2 fire scenario that could result in direct flame impingement on the degraded fire barrier. If necessary, extend the fire spread time analysis to encompass fire spread up to the fire barrier (e.g., along a cable tray) if this was not already done for the selected scenario already.

From the available scenarios meeting these criteria, select the scenario with the shortest FDS fire growth and damage time. This will be used as the representative fire growth time for the FDS3 scenarios.

Assume the inter-compartment fire barrier will successfully confine any fire to the exposing fire area for a period equal to the degraded fire endurance rating. Add the effective fire endurance rating of the inter-compartment fire barrier to the fire growth time.

Add to this time the fire endurance rating for any raceway fire barriers protecting the targets in the exposed fire area.

The result is the total fire damage time:

(fire damage time) = (fire growth time)+(effective fire endurance rating for the inter-compartment fire barrier)+(effective fire endurance rating for raceway fire barriers in the exposed area if available).

Continue to step 2.7. For FDS3 scenarios, use the manual suppression curve for the “All Events” category to estimate fire non-suppression probability regardless of the fire ignition source.

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